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RESEARCH ARTICLE

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Shortening self-report mental health symptom measures through optimal test assembly methods: Development and validation of the Patient Health Questionnaire-Depression-4

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Background: The objective of this study was to develop and validate a short form of the Patient Health Questionnaire-9 (PHQ-9), a self-report questionnaire for assessing depressive symptomatology, using objective criteria.

Methods: Responses on the PHQ-9 were obtained from 7,850 English-speaking participants enrolled in 20 primary diagnostic test accuracy studies. PHQ unidimensionality was verified using confirmatory factor analysis, and an item response theory model was fit. Optimal test assembly (OTA) methods identified a maximally precise short form for each possible length between one and eight items, including and excluding the ninth item. The final short form was selected based on prespecified validity, reliability, and diagnostic accuracy criteria.

Results: A four-item short form of the PHQ (PHQ-Dep-4) was selected. The PHQ-Dep-4 had a Cronbach's alpha of 0.805. Sensitivity and specificity of the PHQ-Dep-4 were 0.788 and 0.837, respectively, and were statistically equivalent to the PHQ-9 (sensitivity = 0.761, specificity = 0.866). The correlation of total scores with the full PHQ-9 was high ($r = 0.919$).

Conclusion: The PHQ-Dep-4 is a valid short form with minimal loss of information of scores when compared to the full-length PHQ-9. Although OTA methods have been used to shorten patient-reported outcome measures based on objective, prespecified criteria, further studies are required to validate this general procedure for broader use in health research. Furthermore, due to unexamined heterogeneity, there is a need to replicate the results of this study in different patient populations.

KEYWORDS

depression, Patient Health Questionnaire, patient outcome assessment, psychometrics

1 | INTRODUCTION

In mental health research and clinical practice, self-report symptom measures are used to assess patient symptoms and identify patients with undetected mental disorders. Completing these measures is demanding, especially when people are asked to respond to multiple measures that each contain multiple items (Coste, Guillemin, Pouchot, & Fermanian, 1997; Goetz et al., 2013; Kruijen, Emons, & Sijtsma, 2013; Stanton, Sinar, Balzer, & Smith, 2002). Therefore, researchers attempt to create shortened versions with

scores that perform comparably well with original full-length versions (Coste et al., 1997; Goetz et al., 2013; Kruijen et al., 2013; Stanton et al., 2002).

The Patient Health Questionnaire-9 (PHQ-9) is a nine-item, self-report questionnaire that measures depressive symptomatology (Kroenke & Spitzer, 2002; Kroenke et al., 2009; Kroenke, Spitzer, & Williams, 2001). A recent meta-analysis of the PHQ-9 found that at the standard cutoff of 10, based on 34 studies, the sensitivity and specificity were 0.78 and 0.87, respectively (Moriarty, Gilbody, McMillan, & Manea, 2015).

The PHQ-8 is similar to the PHQ-9 and is increasingly used because it eliminates one item that asks about patients' thoughts of either self-harm or being "better off dead" (Kroenke & Spitzer, 2002), but it identifies large numbers of patients not at risk of suicide (Dube, Kroenke, Bair, Theobald, & Williams, 2010; Razykov, Hudson, Baron, & Thombs, 2013). Many studies have reported that the PHQ-8 performs nearly identically to the PHQ-9 (Corson, Gerrity, & Dobscha, 2004; Kroenke & Spitzer, 2002; Leadbeater, Carruthers, Green, Rosser, & Field, 2011; Razykov et al., 2013).

The PHQ-2 is another short-form, designed to include the two core items in a Diagnostic and Statistical Manual of Mental Disorders (DSM) Major Depressive Disorder (MDD) diagnosis: depressed mood and anhedonia (Kroenke, Spitzer, & Williams, 2003). A recent meta-analysis of the PHQ-2 found that at a cutoff of 2, based on 17 studies, the sensitivity and specificity were 0.91 and 0.70, respectively, whereas at a cutoff of 3, based on 19 studies, the sensitivity and specificity were 0.76 and 0.87, respectively (Manea et al., 2016).

Conventionally, short forms of patient-reported measures are created through an expert-based analysis of item content, as with the PHQ-2, or by removing items with minimal factor loadings (Goetz et al., 2013). These methods are not typically applied in a systematic way, and multiple shortened versions of the same measure may exist (Coste et al., 1997; Goetz et al., 2013; Kruiyen et al., 2013; Smith, McCarthy, & Anderson, 2004; Stanton et al., 2002). Methods such as item response theory (IRT; van der Linden & Hambleton, 2013) have been used to evaluate and identify problematic items, but have not incorporated objective and reproducible criteria for item selection.

Optimal test assembly (OTA) is a mixed-integer programming procedures that uses an estimated IRT model to select the subset of items that best satisfies prespecified constraints (van der Linden, 2006). Although more commonly used in the development of high-stakes educational tests (Holling, Kuhn, & Kiefer, 2013), a recent study demonstrated that OTA can be used to develop shortened versions of patient-reported outcome measures (A. W. Levis et al., 2016). This procedure was also shown to be replicable, reproducible, and produce shortened forms of minimal length as compared with leading alternative methods (Harel & Baron, 2018).

The objective of the present study was to apply OTA to develop a shortened version of the PHQ-9. We (a) used confirmatory factor analysis to verify the unidimensionality of the underlying construct; (b) applied OTA methods to obtain candidate forms of each possible length; and (c) selected the shortest possible form that showed similar performance to the full form in terms of prespecified validity, reliability, and diagnostic accuracy criteria, compared to the PHQ-9 as the full-form standard.

2 | MATERIALS AND METHODS

This study used a subset of data accrued for an individual participant data meta-analysis (IPDMA) on the diagnostic accuracy of the PHQ-9 depression screening tool to detect major depression (in progress). The IPDMA was registered in PROSPERO

(CRD42014010673), and a protocol was published (Thombs et al., 2014).

2.1 | Search strategy

A medical librarian searched Medline, Medline In-Process, and Other Nonindexed Citations via Ovid, PsycINFO, and Web of Science (January 2000 to December 2014) on February 7, 2015, using a peer-reviewed search strategy (Supporting Information Methods 1). We also reviewed reference lists of relevant reviews and queried contributing authors about nonpublished studies. Search results were uploaded into RefWorks (RefWorks-COS, Bethesda, MD). After deduplication, unique citations were uploaded into DistillerSR (Evidence Partners, Ottawa, Canada), for storing and tracking search results.

2.2 | Identification of eligible studies for full IPDMA

Datasets from articles in any language were eligible for inclusion if they included diagnostic classifications for current MDD or Major Depressive Episode (MDE) based on a validated semistructured or fully structured interview conducted within 2 weeks of PHQ-9 administration, among participants ≥ 18 years and not recruited from youth or psychiatric settings. Datasets where not all participants were eligible were included if primary data allowed selection of eligible participants. For defining major depression, we considered MDD or MDE based on the DSM or MDE based on the International Classification of Diseases (ICD). If more than one was reported, we prioritized DSM over ICD and DSM MDE over DSM MDD. Across all studies, there were 23 discordant diagnoses depending on classification prioritization (0.1% of participants).

Two investigators independently reviewed titles and abstracts for eligibility. If either deemed a study potentially eligible, full-text review was completed by two investigators, independently, with disagreements resolved by consensus, consulting a third investigator when necessary. Translators were consulted to evaluate titles, abstracts, and full-text articles.

2.3 | Data contribution and synthesis

Authors of eligible datasets were invited to contribute de-identified primary data. We compared published participant characteristics and diagnostic accuracy results with results from raw datasets and resolved any discrepancies in consultation with the original investigators.

2.4 | Data selection for present study

We restricted our dataset to participants who completed the PHQ-9 in English, due to the potential for heterogeneity across studies conducted in different languages. We excluded studies that classified major depression using the Mini International Neuropsychiatric Interview (MINI), because it is structurally different from other fully structured interviews and classifies approximately twice as many participants as cases compared to the most commonly used fully

structured interview, the Composite International Diagnostic Interview (CIDI; B. Levis et al., 2018).

2.5 | Measure

Scores on each PHQ-9 item reflect frequency of symptoms in the last 2 weeks and range from 0 ("not at all") to 3 ("nearly every day"). Higher scores indicate greater depressive symptomatology. Total scores range from 0 to 27 (Kroenke et al., 2001).

2.6 | Statistical analyses

2.6.1 | Verification of unidimensionality of the PHQ-9

Robust weighted least squares estimation in Mplus was used to fit a single-factor confirmatory factor analysis model of PHQ-9 items (Muthén & Muthén, 2012). The model was first fit without allowing for any residual correlations among the items. Then modification indices were used to identify item pairs that would improve model fit if their residuals were allowed to correlate, if there was theoretical justification (McDonald & Ho, 2002). Model fit was evaluated concurrently, using: the χ^2 statistic, comparative fit index (CFI), Tucker–Lewis index (TLI), and root mean square error of approximation (RMSEA; Chen, Curran, Bollen, Kirby, & Paxton, 2008). Priority was given to CFI, TLI, and RMSEA, because the χ^2 test may reject well-fitting models when sample size is large (Reise, Widaman, & Pugh, 1993). Model fit was considered adequate if CFI and TLI ≥ 0.95 and RMSEA ≤ 0.08 (Hu & Bentler, 1999).

2.6.2 | Item response theory model and optimal test assembly

A generalized partial credit model (GPCM) was fit to PHQ-9 (Muraki, 1992). The GPCM is an IRT model that relates a latent trait, representing severity of depressive symptomatology, to the distribution of observed item-level responses. The GPCM estimates two types of item-specific parameters: a discrimination parameter and threshold parameters. From these item-level parameter estimates, item information functions for each item were calculated from the GPCM, as well as a test information function (TIF), obtained by summing item information functions. Because the TIF is inversely related to the standard error of measurement of the latent trait, high amounts of information represent greater precision for measuring depressive symptomatology.

Next, we used OTA, a mixed-integer programming technique to systematically search for the short form that maximized the TIF, subject to the constraint of fixing the number of items included in each short form, optimizing the precision of the short form in estimating participants' level of depressive symptomatology (Boekkooi-Timminga, 1989; van der Linden, 2006). The shape of the TIF was anchored at five points (van der Linden, 2006). Thus, for each short form of lengths one to eight items, OTA selected items from the full set of the nine PHQ-9 items that maximized test information. Due to concerns about the use of the ninth item of the PHQ (Corson et al., 2004; Dube et al., 2010; Lee, Schulberg, Raue, & Kroenke, 2007; Razykov et al., 2013; Rief, Nanke,

Klaiberg, & Braehler, 2004), the same procedure was used to generate eight additional short forms that were forced to exclude the ninth item. In total, the OTA procedure yielded 16 candidate short forms.

For each of the 16 candidate short forms and the full-length form, two scoring procedures were used to obtain estimates of each participant's level of depressive symptomatology. First, the summed scores across all items included in the short form were calculated. Second, factor scores were estimated for each participant. Although summed scores are typically relied upon for clinical use, the factor scores were considered to provide a better estimate of the latent trait due to well-known limitations of the summed score under the GPCM (Harel, 2014; van der Ark, 2005).

2.6.3 | Selection of final short form

The selection of the final short form was based on the following five criteria: reliability, concurrent validity of summed scores, concurrent validity of factor scores, and noninferior sensitivity and specificity, because the elimination of items necessarily reduces information compared to a full-length form.

Reliability of each candidate short form was assessed with Cronbach's alpha (Cronbach, 1951). The final selected form was required a priori to have a Cronbach's alpha coefficient ≥ 0.80 . Concurrent validity of the summed scores and factor scores was measured with the Pearson's correlation coefficient between the full-length form and candidate short form scores, and were required a priori to be ≥ 0.90 .

Diagnostic accuracy of each candidate short form was assessed through a three-step process. First, the sensitivity and specificity of each candidate short form for each of its possible cutoff summed score values were estimated with a bivariate random-effects model. Second, for each candidate short form, an optimal cutoff score was selected using Youden's J statistic (Youden, 1950). For the full-length form, the conventionally used cutoff score of 10 was selected (Gilbody, Richards, Brealey, & Hewitt, 2007; Kroenke & Spitzer, 2002; Kroenke et al., 2001; Spitzer, Kroenke, & Williams, 2000; Wittkampf, Naeije, Schene, Huyser, & van Weert, 2007). Third, two noninferiority tests were conducted for each of the 16 candidate forms to compare sensitivity and specificity, separately, to the full-length form. Noninferiority tests assess whether the sensitivity or specificity of the short form is not lower than that of the full-length form, up to a prespecified clinically significant tolerance (Counsell & Cribbie, 2015), such as $\delta = 0.05$. To conduct the noninferiority test, the sampling distribution of the test statistic was generated through the bootstrap method (Liu, Ma, Wu, & Tai, 2006). Bootstrapping resamples the original dataset, with replacement, to generate new, artificial, datasets (Efron & Tibshirani, 1994). For each noninferiority test, 2,000 bootstrap iterations were conducted, controlling in each for the number of respondents with and without major depression. For each bootstrap iteration, the bivariate random-effects model was fit to each of the 16 candidate short forms and the full-length form, and the sensitivities and specificities were computed based on their cutoff scores. To account for the multiple testing in the 32 total noninferiority tests, the Benjamini–Hochberg adjusted *P*-value was used to determine the significance of the test at the 0.05 significance level (Benjamini & Hochberg, 1995).

The factor analysis was conducted using Mplus 7 (Muthén & Muthén, 2012). All other analyses were conducted using R version 3.3.3 (R Core Team, 2017). The GPCM was fit using the *ltm* package (Rizopoulos, 2006). The OTA analysis was conducted using the *lpSolveAPI* package (Diao & van der Linden, 2011). The bivariate random-effects model was fit using the *lme4* package (Bates, Mächler, Bolker, & Walker, 2015).

3 | RESULTS

3.1 | Search results and inclusion of primary data

Of 5,248 unique titles and abstracts identified from the database search, 5,039 were excluded after title and abstract review and 113 after full-text review, leaving 96 eligible articles with data from 69 unique participant samples, of which 55 (80%) contributed datasets (Supporting Information Figure 1). Authors of included studies contributed data from three unpublished studies, for a total of 58 datasets. Of these, we excluded 32 studies that administered the PHQ-9 in a language other than English and six more that used the MINI. In total, 7,850 participants (863 major depression cases) from 20 primary studies were included. These studies were conducted in the United States, New Zealand, Australia, Canada, the United Kingdom, and Cameroon. The mean age of the sample was 33.9 years, and 55.3% of participants were women. (See Table 1 for descriptive sample statistics, and Supporting Information Table 1 for characteristics of each included study.)

3.2 | Unidimensionality of PHQ-9

A single-factor model was fit to the PHQ-9 items with no specification of residual correlations ($\chi^2 [df = 36] = 1578.7, P < 0.0001, TLI = 0.966, CFI = 0.974, RMSEA = 0.086$). Modification indices indicated improvement of model fit if residuals of items that measure physical symptoms (items 3, 4, and 5) were correlated. The model was refitted with specification of three correlated residuals, and fit improved ($\chi^2 [df = 39] = 750.2, P < 0.0001, TLI = 0.982, CFI = 0.988, RMSEA = 0.062$). Factor loadings for items were all moderately high, with a median of 0.763 and a range of 0.665–0.877.

3.3 | Item response theory model and optimal test assembly

Table 2 presents discrimination parameters for each item based on the GPCM. The item with the greatest discrimination parameter was item 2. Other items with high values were items 1 and 6. Figure 1 shows the information function of each of the nine items, as well as the total TIF.

Table 3 shows the items that were included in each of the 16 candidate short forms from the OTA analysis. For the candidate forms generated both with the inclusion of item 9 and without, items 3, 4, and 5 were only selected in the longest short forms, and quickly dropped thereafter. Items 1, 2, and 6 were included in all forms of at least four items. For the short forms generated from the full set of nine items, item 9 was included in all candidate short forms.

TABLE 1 Patient demographic and diagnostic characteristics (N = 7,850)

Sociodemographic variables	Summary
Age, years, mean [median] \pm SD (range)	52.0 [54] \pm 18.1 (18, 102)
Women, n (%)	4,335 (55.2)
PHQ-9 score, mean [median] \pm SD (range)	5.2 [3] \pm 5.4 (0, 27)
Country, n (%)	
USA	2,781 (35.4)
New Zealand	2,528 (32.2)
Australia	1,092 (13.9)
Canada	573 (7.3)
UK	478 (6.1)
Cameroon	398 (5.1)
Care setting, n (%)	
Primary care	2,928 (37.3)
Nonmedical setting	1,389 (17.7)
Perinatal care	665 (8.5)
Neurology	607 (7.7)
HIV/AIDS care	398 (5.1)
Oncology	273 (3.5)
Medical rehabilitation	211 (2.7)
Rheumatology	201 (2.6)
Cardiology	100 (1.3)
Stroke care	72 (0.9)
Outpatients with coronary artery disease	1,006 (12.8)
Diagnostic interview, n (%)	
CIDI	3,949 (50.3)
SCID	2,443 (31.1)
DIS	1,006 (12.8)
SCAN	352 (4.5)
DISH	100 (1.3)
Classification system, n (%)	
DSM-IV	6,859 (87.4)
ICD-10	822 (10.5)
DSM-5	169 (2.2)

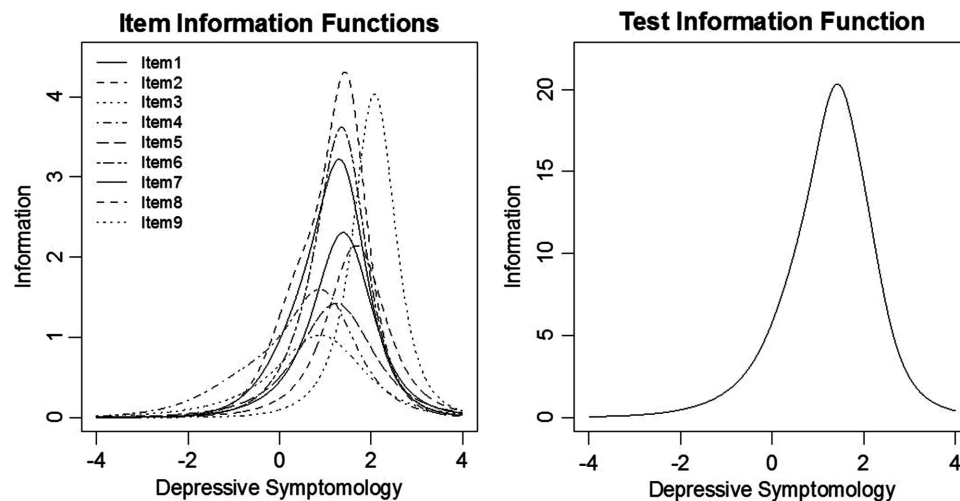
3.4 | Selection of final short form

Table 4 presents Cronbach's alpha values and concurrent validity correlations for the 16 candidate short forms. Table 5 presents results of the noninferiority tests for both sensitivity and specificity. There were four short forms that satisfied our prespecified criteria in terms of reliability, concurrent validity, and diagnostic accuracy. The four such forms were: six-item and seven-item short forms that included item 9 and four-item and five-item short forms that excluded item 9.

The four-item short form was the shortest form that fulfilled all criteria. The form includes: item 1 ("Little interest or pleasure in doing things"), item 2 ("Feeling down, depressed, or hopeless"), item 6 ("Feeling bad about yourself—or that you are a failure or have let yourself or your family down"), and item 8 ("Moving or speaking so slowly that other people could have noticed? Or the opposite—being so

TABLE 2 PHQ-9 items and discrimination parameters from the generalized partial credit model

Item number	Description	Discrimination parameter
1	Little interest or pleasure in doing things	1.95
2	Feeling down, depressed, or hopeless	2.40
3	Trouble falling or staying asleep, or sleeping too much	0.93
4	Feeling tired or having little energy	1.37
5	Poor appetite or overeating	1.08
6	Feeling bad about yourself—or that you are a failure or have let yourself or your family down	1.90
7	Trouble concentrating on things, such as reading newspaper or watching television	1.41
8	Moving or speaking so slowly that other people could have noticed? Or the opposite—being so fidgety or restless that you have been moving around a lot more than usual	1.29
9	Thoughts that you would be better off dead or of hurting yourself in some way	1.77

**FIGURE 1** The left hand plot shows the item information functions for each of the 9 items. The right hand plot shows the test information function of the PHQ-9

fidgety or restless that you have been moving around a lot more than usual"). The PHQ-Dep-4 maintained high reliability with a Cronbach's alpha of 0.805 (95% CI, 0.795, 0.814) compared to 0.866 for the full-length form. Correlations of the summed and factor scores between the PHQ-Dep-4 and PHQ-9 were 0.919 (95% CI, 0.916, 0.923) and 0.910 (95% CI, 0.907, 0.914), respectively. The sensitivity and specificity of the PHQ-Dep-4 at its optimal cutoff of 4 were 0.788 (95% CI, 0.725, 0.840) and 0.837 (95% CI, 0.809, 0.861), respectively. Both sensitivity and specificity were noninferior to the sensitivity (0.761; 95% CI, 0.679, 0.787) and specificity (0.866; 95% CI, 0.836, 0.892) of the full-length form.

4 | DISCUSSION

This study illustrated how OTA methods can be used to effectively shorten self-report symptom measures while maintaining comparable diagnostic accuracy. OTA methods were applied to shorten the nine-item PHQ-9 to a four-item version (PHQ-Dep-4). In addition to maintaining similar sensitivity and specificity, the short form had minimal loss of information and maintained reliability and validity that were comparable to the full-length form based on prespecified criteria.

Cronbach's alpha of the PHQ-Dep-4 was 0.805, compared to 0.866 for the full form. Correlations of the summed score and factor score of the PHQ-Dep-4 and PHQ-9 were 0.919 and 0.910, respectively. As per prespecified criteria, the sensitivity and specificity of the PHQ-Dep-4 (0.788 and 0.837, respectively) were within 5% of those of the PHQ-9 (0.761 and 0.866, respectively).

The four items included in the PHQ-Dep-4 included items 1, 2, 6, and 8 from the original PHQ-9. These items included the two core depression items (depressed mood and loss of interest) that make up the commonly used PHQ-2. According to diagnostic criteria for major depression, at least one of these symptoms must be present for a diagnosis. The other two items in the PHQ-Dep-4 included an affective/cognitive item (feelings of failure) and a somatic item (physical movement). Thus, the PHQ-Dep-4 includes items that qualitatively represent the depressive symptomatology construct well. We note that the PHQ-Dep-4 includes one somatic symptom, whereas the full PHQ-9 includes four symptoms. One study found that somatic symptoms may increase scores on the PHQ-9 among somatically ill patients due to factors related to somatic disease, but not depression, among scleroderma patients, but the association was minimal (Leavens, Patten, Hudson, Baron,

TABLE 3 Items included in optimal short forms of each length with item 9 included and item 9 excluded

Item number (X indicates inclusion)									
Short form length	1 Little interest	2 Feeling down	3 Sleep problem	4 Feeling tired	5 Appetite	6 Feeling failure	7 Concentration	8 Physical movement	9 Thoughts of death or self-harm
Item 9 eligible for inclusion in short forms									
1									X
2		X							X
3	X	X							X
4	X	X				X			X
5	X	X				X		X	X
6	X	X				X	X	X	X
7	X	X		X		X	X	X	X
8	X	X		X	X	X	X	X	X
Item 9 ineligible for inclusion in short forms									
1		X							
2	X	X							
3	X	X				X			
4	X	X				X		X	
5	X	X				X	X	X	
6	X	X		X		X	X	X	
7	X	X		X	X	X	X	X	
8	X	X	X	X	X	X	X	X	

TABLE 4 Reliability and validity results of the candidate short forms

Form length	Cronbach's alpha (95% CI)	Correlation of summed scores (95% CI)	Correlation of factor scores (95% CI)
Item 9 eligible for inclusion in short forms			
1	NA	0.527 (0.511, 0.543)	NA
2	0.533 (0.504, 0.563)	0.804 (0.796, 0.811)	0.800 (0.792, 0.808)
3	0.727 (0.712, 0.741)	0.863 (0.857, 0.868)	0.869 (0.863, 0.874)
4	0.801 (0.790, 0.810)	0.892 (0.887, 0.896)	0.895 (0.890, 0.899)
5	0.809 (0.799, 0.819)	0.920 (0.916, 0.923)	0.912 (0.909, 0.916)
6	0.835 (0.826, 0.843)	0.939 (0.937, 0.942)	0.931 (0.928, 0.934)
7	0.846 (0.839, 0.854)	0.971 (0.970, 0.973)	0.980 (0.979, 0.980)
8	0.858 (0.851, 0.865)	0.986 (0.986, 0.987)	0.989 (0.989, 0.990)
9	0.866 (0.860, 0.873)	1.000 (1.000, 1.000)	1.000 (1.000, 1.000)
Item 9 ineligible for inclusion in short forms			
1	NA	0.781 (0.772, 0.79)	NA
2	0.779 (0.763, 0.794)	0.849 (0.842, 0.855)	0.860 (0.855, 0.866)
3	0.816 (0.806, 0.826)	0.887 (0.882, 0.892)	0.891 (0.886, 0.895)
4	0.805 (0.795, 0.814)	0.919 (0.916, 0.923)	0.910 (0.907, 0.914)
5	0.832 (0.824, 0.840)	0.940 (0.936, 0.941)	0.930 (0.927, 0.933)
6	0.845 (0.838, 0.852)	0.970 (0.969, 0.971)	0.978 (0.977, 0.979)
7	0.857 (0.850, 0.863)	0.984 (0.984, 0.985)	0.988 (0.987, 0.988)
8	0.866 (0.860, 0.872)	0.997 (0.997, 0.997)	0.998 (0.998, 0.998)

Note: Bold values represent those of the final selected form.

TABLE 5 Diagnostic accuracy results of the candidate short forms and their noninferiority test results

Form length	Optimal cutoff	Sensitivity (95% CI)	P-value	Specificity (95% CI)	P-value
Item 9 eligible for inclusion in short forms					
1	1	0.420 (0.369, 0.437)	0.976	0.943 (0.930, 0.954)	0.000
2	1	0.929 (0.900, 0.950)	0.000	0.650 (0.592, 0.685)	0.976
3	2	0.892 (0.843, 0.927)	0.000	0.717 (0.680, 0.751)	0.976
4	3	0.858 (0.810, 0.895)	0.000	0.776 (0.744, 0.805)	0.976
5	4	0.806 (0.749, 0.853)	0.000	0.826 (0.798, 0.851)	0.066
6	5	0.837 (0.808, 0.863)	0.000	0.837 (0.808, 0.863)	0.000
7	7	0.814 (0.715, 0.884)	0.000	0.849 (0.820, 0.873)	0.000
8	7	0.856 (0.855, 0.857)	0.000	0.802 (0.801, 0.804)	0.976
9	10	0.761 (0.679, 0.787)	NA	0.866 (0.836, 0.892)	NA
Item 9 ineligible for inclusion in short forms					
1	1	0.916 (0.877, 0.944)	0.000	0.650 (0.599, 0.698)	0.976
2	2	0.880 (0.825, 0.919)	0.000	0.725 (0.688, 0.760)	0.976
3	3	0.844 (0.796, 0.882)	0.000	0.784 (0.752, 0.813)	0.976
4	4	0.788 (0.725, 0.840)	0.000	0.837 (0.809, 0.861)	0.000
5	5	0.792 (0.716, 0.873)	0.000	0.848 (0.820, 0.873)	0.000
6	6	0.855 (0.762, 0.916)	0.000	0.807 (0.773, 0.838)	0.976
7	7	0.844 (0.762, 0.902)	0.000	0.810 (0.776, 0.840)	0.976
8	8	0.871 (0.786, 0.925)	0.000	0.784 (0.746, 0.819)	0.976

Note: Bold values represent those of the final selected form.

& Thombs, 2012). Another study, of multiple sclerosis patients, did not find that somatic symptoms influenced scores substantively (Sjonnese et al., 2012).

Both the actual PHQ-2 and the PHQ-8 were selected in the set of 16 candidate short forms. Neither of these, however, were selected by the OTA procedure as optimal. The PHQ-Dep-4 has lower sensitivity than the PHQ-2 (0.788 rather than 0.880), but higher specificity (0.837 rather than 0.725). The PHQ-Dep-4, therefore, may represent a middle ground between shortening the full-length scale, while still retaining desirable measurement and diagnostic properties. The PHQ-Dep-4 may be a useful option in some contexts because it is shorter than the PHQ-9 and PHQ-8, but generates a wider score distribution than the PHQ-2.

There are several limitations for this study that must be considered. First, for the collection of data for the full IPDMA, it was not possible to obtain primary data from 14 of the 69 eligible datasets. Second, the full IPDMA excluded studies where the PHQ-9 was administered exclusively to patients with known psychiatric conditions. Therefore, the generalizability of the results should be confirmed when monitoring treatment response. Third, the present study only included participants for whom the PHQ-9 was administered in English. Fourth, a previous study showed that semistructured and fully structured interviews have different characteristics as reference standards (B. Levis et al., 2018). We excluded studies that used the MINI, given its high rate of diagnosis relative to other diagnostic interviews (B. Levis et al., 2018). We included studies that used both semistructured and fully structured interviews as reference standards, and future work should verify that our results apply in both cases. Although our dataset included a specific sample of patients, we note that measurement

invariance or differential item functioning requirements have been examined in previous studies of the PHQ-9 used as a continuous measure across variables such as language (Arthurs, Steele, Hudson, Baron, & Thombs, 2012; Merz, Malcarne, Roesch, Riley, & Sadler, 2013), culture (Baas et al., 2011; Hirsch, Donner-Banzhoff, & Bachmann, 2013; Huang, Chung, Kroenke, Delucchi, & Spitzer, 2006), and medical diagnosis (Chung et al., 2015; Cook et al., 2011; Leavens et al., 2012). These studies provide some degree of confidence that the structure of the PHQ-9 is similar across groups. Lastly, there is a need to replicate our results in different patient populations due to unexamined heterogeneity across the studies included in this analysis.

With regard to the OTA procedure, two limitations must be considered. First, the selection of a short version was sensitive to the choice of criteria for the selection of the final form, and should be carefully considered in future analyses. Additionally, the OTA approach is exploratory and data-driven, and the results of this study should be replicated.

5 | CONCLUSION

The study illustrates how patient self-report symptom measures can be developed and validated using the OTA method, which uses pre-specified objective criteria to determine the length and specific items that should be included in a short form. The method was implemented with a sample of 7,850 participants from 20 primary PHQ-9 diagnostic studies. The four-item version was developed and validated based on prespecified constraints on its test information, reliability, validity, and diagnostic accuracy.

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CONFLICTS OF INTEREST

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AUTHOR CONTRIBUTIONS

MI, DH, BL, PC, SG, JPAI, LAK, DM, SBP, IS, RJS, RCZ, AB, and BDT were responsible for the study conception and design. BA, MB, CHB, PB, GC, KC, YC, DKG, FGS, CGG, JH, PAH, MH, KI, NJ, KMK, LM, AM, BWP, AGR, A. Sidebottom, A. Simning, AT, JW, MAW, KW, AB, and BDT were responsible for collection of primary data included in this study. BL, KER, NS, MA, DBR, TAS, MJC, and BDT contributed to data extraction and coding. MI, DH, BL, AWL, AB, and BDT contributed to the data analysis and interpretation. MI, DH, BL, AWL, and BDT contributed to drafting the manuscript. All authors provided a critical review and approved the final manuscript. DH is the guarantor.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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